ARS 42-89
September 1963

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

TERMINAL VELOCITIES OF SMALL FRUITS

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A falling object will accelerate under a force of gravity until a maximum constant velocity is reached. The terminal velocity or any end velocity of small fruit is important because:

1. The application of the tree-shaking method of harvesting fruit is dependent upon holding fruit damage to a minimum. The velocity at the point of impact of a falling fruit is the main factor causing fruit injury.

2. Smaller fruit can be separated from larger fruit through the use of forced air if the velocity of the forced air is between the terminal velocity of the small fruit and the terminal velocity of the larger fruit. This method of culling is presently being used with blueberries and may be extended to other fruits such as cherries.

During the summer of 1962, a study was conducted to determine terminal velocities of falling blueberries, grapes, cherries, and cranberries. Terminal velocities of fruits have not heretofore been determined by tracking falling fruit. Earlier work, however, has been done in determining terminal velocity by study of air velocity required to float fruit.[2/] Prior to the experimental work, terminal velocities were determined on a theoretical basis.

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2/ Quackenbush, H. E., Stout, B. A., and Ries, K. E. "Pneumatic Tree-Fruit Harvesting," Agricultural Engineering, Vol. 43, No. 7: 388-393. July 1962.

Theoretical Calculations of Terminal Velocities

Method A

Terminal velocity is reached when, owing to bouyant and drag forces, gravity no longer accelerates a free falling object or:

weight of the sphere = weight of air displaced + drag force
Expressing this mathematically:

$$D_v = Pv + C_D \frac{P}{g} A \frac{V^2}{2}$$

Where v = volume of the object dropped in cubic inches

D = mass density of the object dropped in pounds per cubic inch

P = mass air density in pounds per cubic inch

g = acceleration due to gravity in inches per second/second

A = area of the object dropped in square inches

C_D = coefficient of drag (dimensionless)

V = terminal velocity in inches per second

The application of this method requires:

1. The assumption of a coefficient of drag (C_D)
2. Solving the equation (above) for velocity
3. Determining the Reynolds number by solving the equation:

$$RE = \frac{Vd}{G}$$

Where G = viscosity of the air in square feet per second

d = diameter of the object in inches

4. Repetition of the above steps until the Reynolds number matches the coefficient of drag as given in published tables or graphs.

Method B

A second method used for theoretically calculating terminal velocity was based on the rate of fall of an object after terminal velocity is reached, varying as the square root of the particle diameter. The mathematical expression as given by Croft[3/] is:

$$V = K \left(d \left(\frac{D}{P} - 1\right)\right)^{1/2}$$

Where K = constant depending upon the shape of the object.

Method B was used to determine the theoretical terminal velocity by a quicker approach. This equation assumes a coefficient of drag.

Measurements of Terminal Velocities

Terminal velocities and the distance offall at which they were reached were determined by dropping the fruit down a 23-foot-high drop chute; when necessary, these objects were started with an initial velocity. The objects fell past a series of phototubes located along the chute. The falling fruit on passing the series of phototubes interrupted light beams. This information was transmitted to an oscillograph where the record consisted of a series of pips spaced in proportion to the velocity of the object and distance between the phototubes. The distance between pips and the chart speed was used to compute the velocities as follows:

$$V = \frac{B \times S}{b}$$

Where V = velocity in inches per second

B = distance between phototubes in inches

b = distance between phototube pips in inches

S = chart speed (9.8425 inches per second)

3/ Croft, H. O., Thermodynamics, Fluid Flow and Heat Transmission, McGraw-Hill Book Company, New York, 1938.

Velocity information computed by this formula was then plotted on the abscissa of the graphs. The dropping heights were plotted as ordinates. Terminal velocities were indicated when the plots lined up vertically. Data needed to extend the curves (with the exception of those for the smaller blueberries) to include the terminal velocity regions was obtained by starting the fruits with an initial velocity. The fruits were ejected into the top of the chute by either a portable pressure-tank arrangement or a rubber band slingshot.

Results

Smaller blueberries reached their terminal velocities when dropped down the 23-foot chute (Fig. 1). The grape, cherry, and cranberry curves were

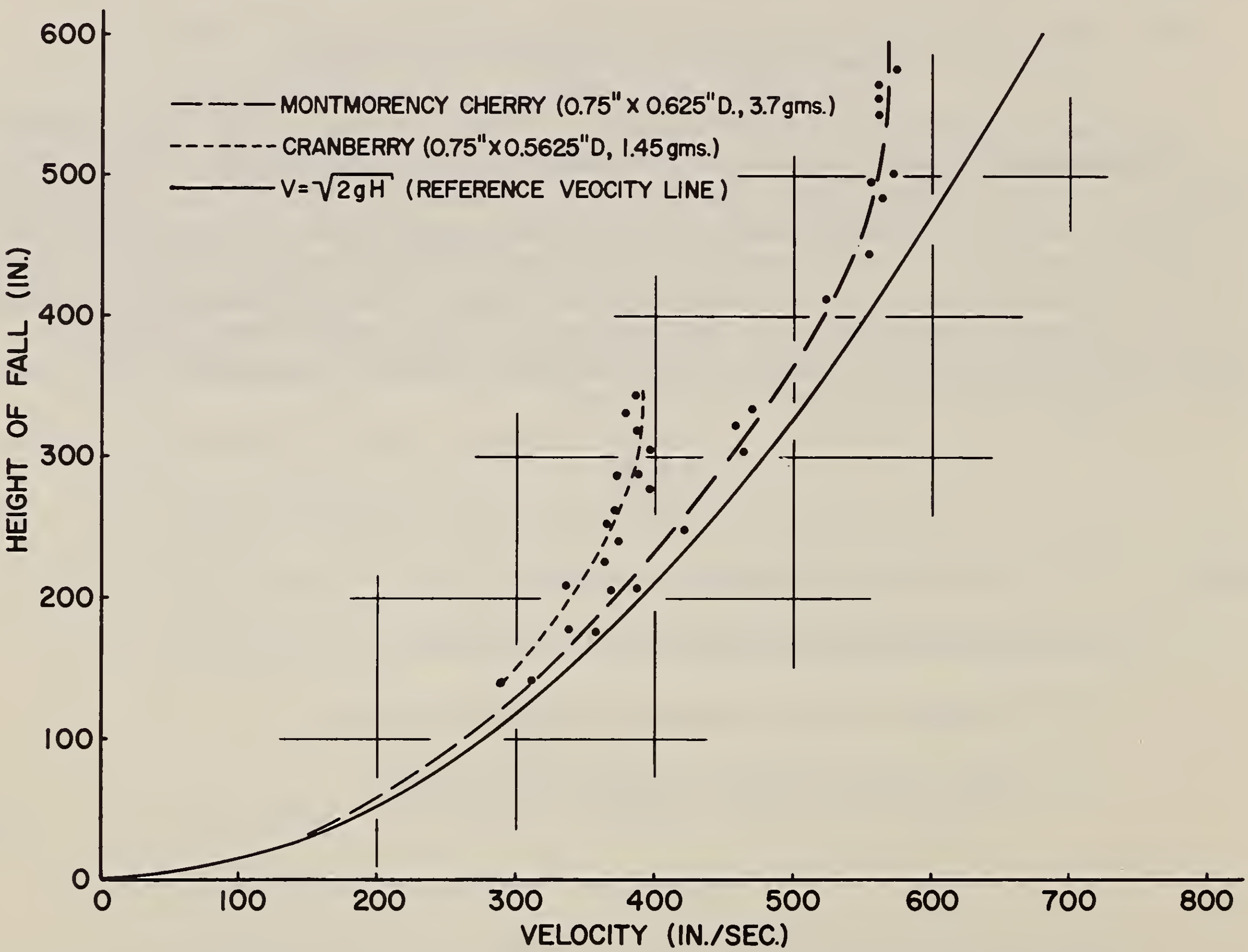

Figure 1. Velocity vs. height of fall - cherries & cranberries.

extended by plotting data collected when the objects were ejected down the chute. By use of the graphs, the velocity of fruit can be determined for any height of drop. The graphs (Figs. 1, 2, and 3) and tabulations (Table 1) summarize the results.

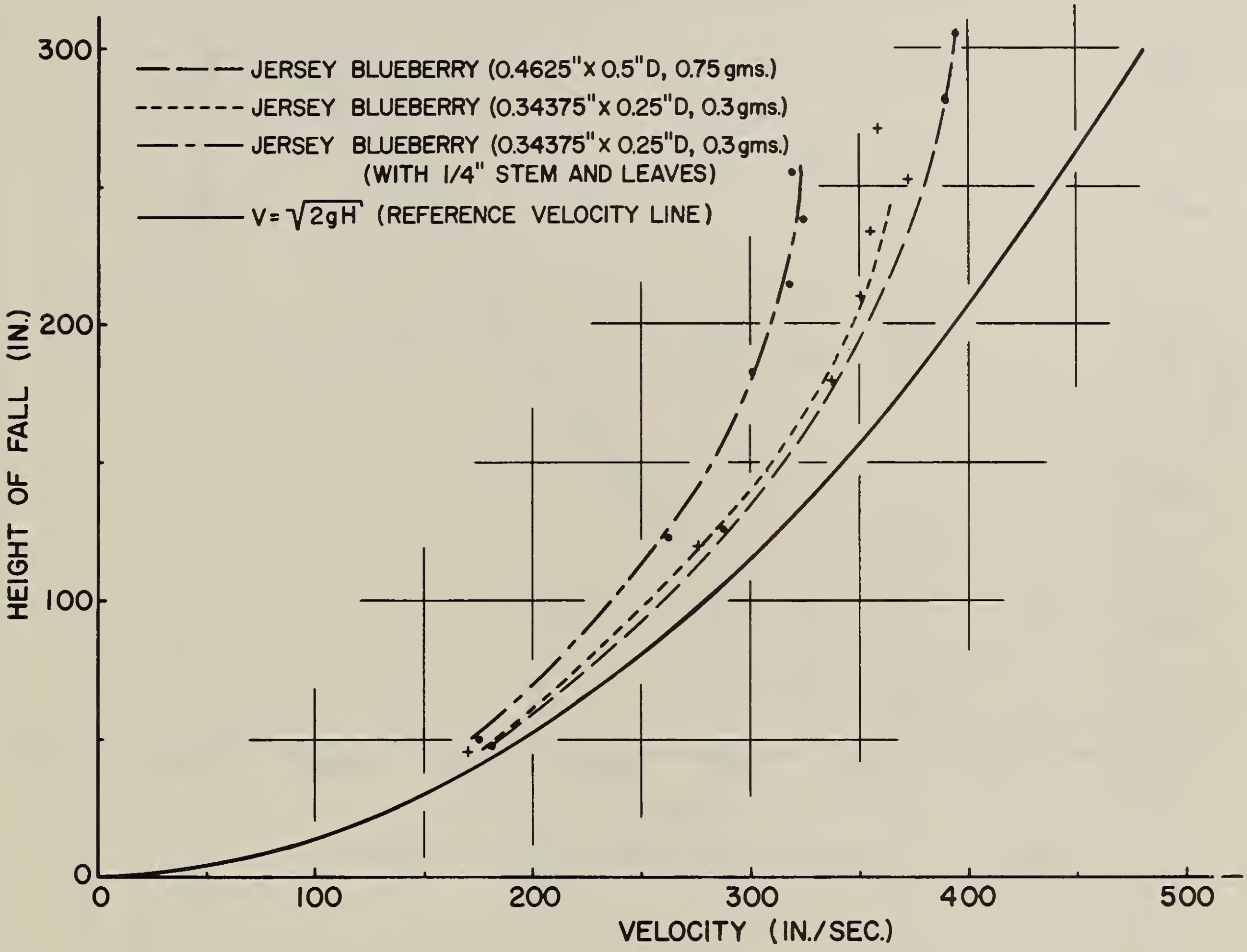

Figure 2. Velocity vs. height of fall-blueberries.

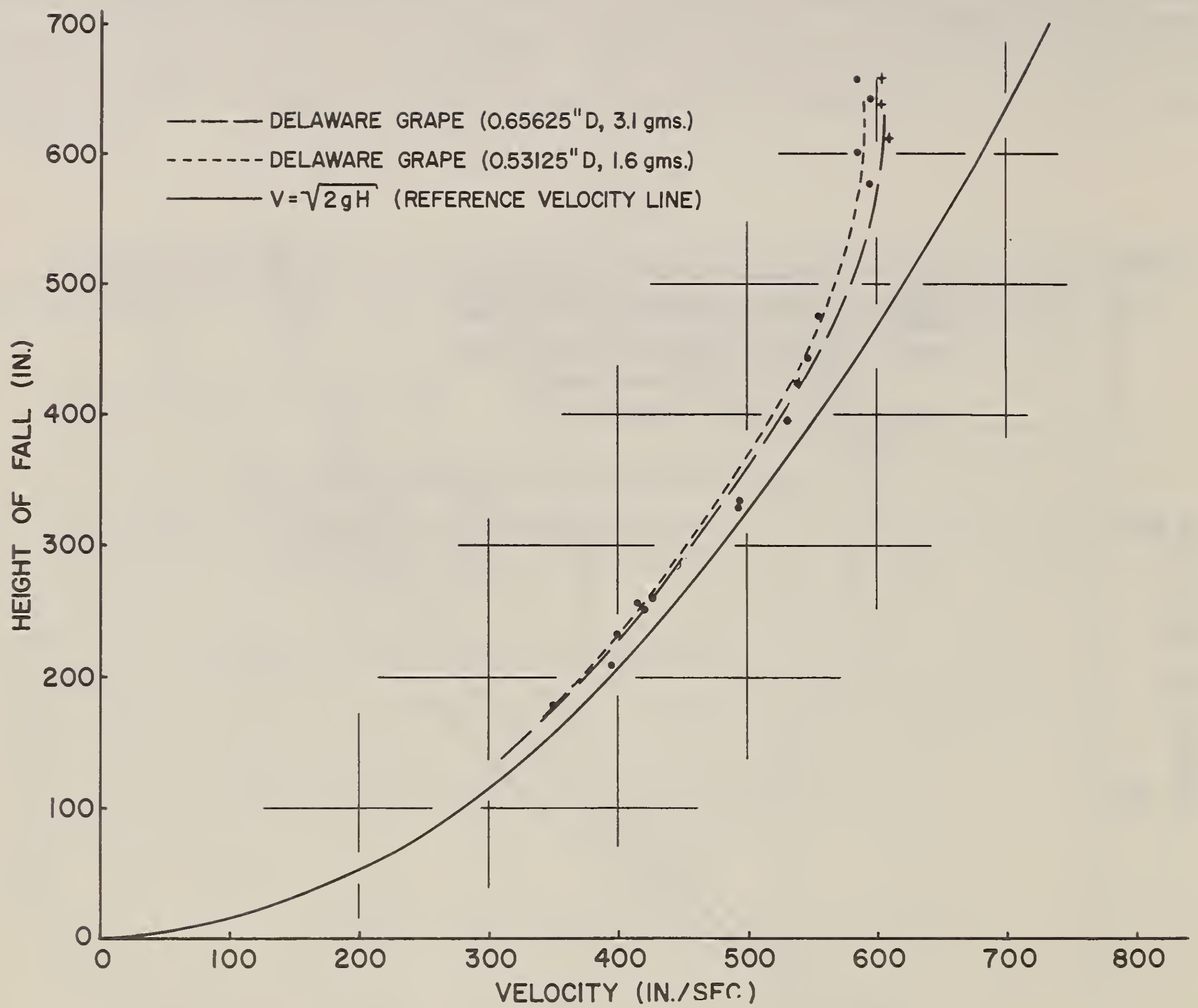

Figure 3. Velocity vs. height of fall-grapes.

Table 1. Terminal velocities of blueberries, grapes, cherries, and cranberries

Fruit	Diameter	Weight	Density	Theoretical Method A	Theoretical Method B	Actual	Standard Deviation (Phototube)
	inches	grams	lb/in^3	All terminal velocities given in inches per second			percent
Jersey blueberry	0.463 x .5 (0.48 average)	0.75	2.80×10^{-2}	622	397	390	1.3
Jersey blueberry	0.344 x 0.25 (0.293 average)	0.30	4.83×10^{-2}	620	407	367	3.7
Jersey blueberry (with stem and leaves)	0.344 x 0.25 (0.293 average)	0.30	4.83×10^{-2}	---	---	320	1.0
Delaware grape	0.5313 round	1.60	4.70×10^{-2}	808	539	590	1.2
Delaware grape	0.6563 round	3.10	4.60×10^{-2}	865	592	605	4.8
Montmorency cherry	0.75 x 0.625 (0.6875 average)	3.7	4.80×10^{-2}	902	618	566	1.2
Cranberry	0.750 x 0.563 (0.6563 average)	1.45	2.16×10^{-2}	612	405	382	2.7

Analysis of Findings

The actual measured terminal velocity of the fruits was considerably smaller than that computed by use of previously published tables and graphs of drag coefficients (Method A, Table 2). This is probably due to the fact

Table 2. Comparison of calculated terminal velocity (Method A) and actual terminal velocity.

Object	Calculated Terminal Velocity (method A)	Actual Terminal Velocity (phototubes)	Error
	in/sec	in/sec	percent
Jersey blueberry 0.463 x 0.50 inch	622	390	+59.4
Jersey blueberry 0.344 x 0.25 inch	620	367	+68.9
Delaware grape 0.5313 inch	808	590	+36.9
Delaware grape 0.6563 inch	865	605	+42.9
Montmorency cherry 0.75 x 0.625 inch	902	566	+59.4
Cranberry 0.750 x 0.563 inch	612	382	+60.2

that the fruit dropped did not have a perfectly spherical shape nor a smooth finish as is assumed in theoretical calculations. The actual measured terminal velocity came closer to that computed by Method B, which assumes the drag coefficient of approximately 1.0, about twice the value given for spheres in published graphs and tables. Comparing the velocities computed by Method B with actual terminal velocities (Table 3), the largest error was 10.9 percent.

Table 3. Comparison of calculated terminal velocity (Method B) and actual terminal velocity.

Object	Calculated Terminal Velocity (Method B)	Actual Terminal Velocity (phototubes)	Error
	in/sec	in/sec	percent
Jersey blueberry 0.463 x 0.50 inch	397	390	+01.8
Jersey blueberry 0.344 x 0.25 inch	407	367	+10.9
Delaware grape 0.5313 inch	539	590	-08.6
Delaware grape 0.6563 inch	592	605	-02.1
Montmorency cherry 0.75 x 0.625 inch	618	566	+09.1
Cranberry 0.750 x 0.563 inch	405	382	+0.60

Conclusion

Actual terminal velocities of certain blueberries, grapes, cherries, and cranberries were determined. Terminal velocities of these fruits can be computed with about 90 percent accuracy by assuming a drag coefficient of 1.0.

Acknowledgments

The authors wish to express appreciation to Richard Wolthuis, USDA Engineering Technician and Leland Fitzpatrick, USDA Engineering Aid, both at East Lansing, Michigan; who aided in the construction of the test equipment and in obtaining and analyzing the test data. Also to Thomas Culhane, Project Engineer, Motor Wheel Corporation, Lansing, Michigan; who supplied the amplifiers and recorder.